



Dual Hardmask Process for the formation of Copper/Low-K
Interconnects

FIELD OF THE INVENTION

5 The invention is generally related to the field of semiconductor devices and fabrication and more specifically to a method for forming copper lines in integrated circuits using a dual hardmask process.

10 BACKGROUND OF THE INVENTION

To increase the operating speed, high performance integrated circuits use copper interconnect technology along with low dielectric constant (low k) dielectrics. Currently the damascene method is the most widely used
15 method for forming copper interconnects. In a via-first dual damascene process, an ILD layer is deposited first, followed by an IMD deposition. An IMD etch-stop layer, such as SiN or SiC, can be optionally used in between IMD and ILD. A via is patterned and etched through the IMD and ILD
20 for connection to lower interconnect levels. Then a trench is patterned and etched in the IMD. A barrier layer and a copper seed layer are then deposited over the structure. The barrier layer is typically tantalum nitride or some other binary transition metal nitride. The copper layer is

electrochemically deposited (ECD) using the seed layer over the entire structure. The copper is then chemically-mechanically polished (CMP'd) to remove the copper over the IMD, leaving copper interconnect lines and vias.

5 During the damascene process a number of photolithograph, etch, and clean-up processes are used. Using the low k dielectric films, a number of unwanted interactions occur between these films and the photolithograph, etch, and clean-up processes. The dry
10 etching of the low k dielectrics, such as organosilicate glass (OSG), often has poor selectivity to photoresist. The selectivity is worsened when 193nm photoresist is used for patterning smaller vias or trenches. Resist erosion during etch can lead to trench and via flaring, and pitting of the
15 dielectric surface. The severity of the problem increases during etch-stop etch and pre-sputter etch when no mask is present to protect the dielectric layer. Severe trench and via flaring, and surface pitting can result in metal shorts. In addition, certain low k material may interact
20 with photoresist and cause resist poisoning. Resist poisoning occurs when chemicals present in low k dielectrics, specifically nitrogen-containing species, diffuse into photoresist films changing the photosensitivity of the photoresist films. This results in

large areas of undeveloped photoresist after the photoresist patterning process. Additional constraints must be applied when ultra-low k dielectrics, often in porous forms, are used in damascene integration schemes. Many of these ultra-low k materials can not be subjected to photoresist ash or wet clean process without irreversible property change. For this reason, a dual hardmask integration scheme is used. Various methods have been utilized to try and reduce the interactions including the use of silicon nitride and silicon carbide hardmasks. A major limitation restricting the use of these various hardmasks is the low etch rate selectivity between the low k dielectric layers and these hardmask layers. Typical etch rate selectivity is in the range of ~ 1:3 to 1:8. There is therefore a need for an improved methodology for forming copper interconnects in integrated circuits, specifically the hardmask selection.

SUMMARY OF THE INVENTION

The present invention describes a dual hardmask process for forming integrated circuit interconnects. Multiple hardmask layers are formed on the upper surface of a single or multiple dielectric layer(s). The dielectric layer or layers is/are formed over a silicon wafer containing numerous electronic devices. A first hardmask is formed on the dielectric layer. This first hardmask comprises silicon carbide or silicon nitride. A second hardmask layer is formed on the first hardmask layer. The second hardmask layer comprises a material selected from the group consisting of titanium aluminide (TiAl), titanium aluminum nitride (TiAlN), titanium nitride (TiN), aluminum nitride (AlN), tantalum aluminide (TaAl), and tantalum aluminum nitride (TaAlN). A patterned photoresist layer and a BARC layer are formed on the second hard mask layer. Following the etching of the second hardmask layer, a new patterned photoresist layer and a new BARC layer are formed. A first trench is etched in the dielectric layer using the second hardmask and/or the photoresist as an etch mask. The exposed portion of the first hardmask is removed and, using the second hardmask as an etch mask, a second trench is formed while simultaneous further etching the first trench.

1990-1991		1991-1992		1992-1993		1993-1994		1994-1995		1995-1996		1996-1997		1997-1998		1998-1999		1999-2000		2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006		2006-2007		2007-2008		2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		2017-2018		2018-2019		2019-2020		2020-2021		2021-2022		2022-2023		2023-2024		2024-2025		2025-2026		2026-2027		2027-2028		2028-2029		2029-2030		2030-2031		2031-2032		2032-2033		2033-2034		2034-2035		2035-2036		2036-2037		2037-2038		2038-2039		2039-2040		2040-2041		2041-2042		2042-2043		2043-2044		2044-2045		2045-2046		2046-2047		2047-2048		2048-2049		2049-2050		2050-2051		2051-2052		2052-2053		2053-2054		2054-2055		2055-2056		2056-2057		2057-2058		2058-2059		2059-2060		2060-2061		2061-2062		2062-2063		2063-2064		2064-2065		2065-2066		2066-2067		2067-2068		2068-2069		2069-2070		2070-2071		2071-2072		2072-2073		2073-2074		2074-2075		2075-2076		2076-2077		2077-2078		2078-2079		2079-2080		2080-2081		2081-2082		2082-2083		2083-2084		2084-2085		2085-2086		2086-2087		2087-2088		2088-2089		2089-2090		2090-2091		2091-2092		2092-2093		2093-2094		2094-2095		2095-2096		2096-2097		2097-2098		2098-2099		2099-2100		2100-2101		2101-2102		2102-2103		2103-2104		2104-2105		2105-2106		2106-2107		2107-2108		2108-2109		2109-2110		2110-2111		2111-2112		2112-2113		2113-2114		2114-2115		2115-2116		2116-2117		2117-2118		2118-2119		2119-2120		2120-2121		2121-2122		2122-2123		2123-2124		2124-2125		2125-2126		2126-2127		2127-2128		2128-2129		2129-2130		2130-2131		2131-2132		2132-2133		2133-2134		2134-2135		2135-2136		2136-2137		2137-2138		2138-2139		2139-2140		2140-2141		2141-2142		2142-2143		2143-2144		2144-2145		2145-2146		2146-2147		2147-2148		2148-2149		2149-2150		2150-2151		2151-2152		2152-2153		2153-2154		2154-2155		2155-2156		2156-2157		2157-2158		2158-2159		2159-2160		2160-2161		2161-2162		2162-2163		2163-2164		2164-2165		2165-2166		2166-2167		2167-2168		2168-2169		2169-2170		2170-2171		2171-2172		2172-2173		2173-2174		2174-2175		2175-2176		2176-2177		2177-2178		2178-2179		2179-2180		2180-2181		2181-2182		2182-2183		2183-2184		2184-2185		2185-2186		2186-2187		2187-2188		2188-2189		2189-2190		2190-2191		2191-2192		2192-2193		2193-2194		2194-2195		2195-2196		2196-2197		2197-2198		2198-2199		2199-2200		2200-2201		2201-2202		2202-2203		2203-2204		2204-2205		2205-2206		2206-2207		2207-2208		2208-2209		2209-2210		2210-2211		2211-2212		2212-2213		2213-2214		2214-2215		2215-2216		2216-2217	
-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--	-----------	--

In the drawings:

5 FIGURES 1(a) - 1(f) are cross-sectional diagrams
illustrating a first embodiment of the instant invention.

FIGURES 2(a) - 2(g) are cross-sectional diagrams illustrating a second embodiment of the instant invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described with reference to Figures 1(a)-1(f) and 2(a)-2(g). It will be apparent to those of ordinary skill in the art that the benefits of the invention can be applied to other structures where a damascene process is utilized.

The requirement of higher clock speed has lead to the use of copper to form the metal interconnect lines in integrated circuits. In addition to the use of copper, dielectric layers such as organosilicate glass (OSG) (dielectric constant $\sim 2.7 - 3.0$) is currently being used to take advantage of the lower dielectric constant of such materials compared to silicon dioxide. In an embodiment of the instant invention, an etch stop layer 30 is formed over a copper layer 20 and a dielectric layer 10. The dielectric layer 10 is formed over a silicon substrate containing various electronic devices such as transistors, diodes, etc. The copper layer 20 represents a portion of the copper interconnect of an integrated circuit which is made up of the electronic devices contained in the silicon substrate. In a multi-level interconnect scheme, layers 10 and 20 described here generally represent the previous

interconnect level. The etch stop layer may comprise silicon nitride (SiN), silicon carbide (SiC), or any suitable material with good etch selectivity and preferably low dielectric constant. Following the formation of the etch stop layer 30, a low k dielectric layer 40 with a low dielectric constant (i.e. less than 3.0) is formed over the etch stop layer 30. In an embodiment of the instant invention this low k dielectric layer 40 comprises organosilicate glass (OSG) which has a dielectric constant of about 2.8. In addition to OSG films, any suitable low k dielectric material may be used to form the dielectric layer 40. Following the formation of the low k dielectric layer 40, a first hardmask layer 50 is formed. This first hardmask layer 50 comprises a material selected from the group consisting of silicon carbide (SiC), silicon nitride (SiN), and any other suitable material. Following the formation of the first hardmask layer 50, a second hardmask layer 60 is formed over the first hardmask layer. This second hardmask layer comprises a material selected from the group consisting of titanium aluminide (TiAl), titanium aluminum nitride (TiAlN), titanium nitride (TiN), aluminum nitride (AlN), tantalum aluminide (TaAl), tantalum aluminum nitride (TaAlN), or any combination of layers of these various alloys. In an embodiment of the instant invention

09904446-090704
TI-31729

Ti_(1-x)Al_xN is used with x varying from 0 to 100% and more preferably from 25% to 40%. For a Ti_(1-x)Al_xN film where x varies from 25% to 40% the etch rate selectivity of OSG to Ti_(1-x)Al_xN is approximately 15:1. Thus, the OSG layer will
5 etch about fifteen times faster than the Ti_(1-x)Al_xN layer. Following the formation of the second hardmask layer 60, a layer of bottom antireflective coating (BARC) 70 and a photoresist layer 80 are formed and patterned as shown in Figure 1(a). The BARC layer 70 is an optional layer.

10
15
20

Shown in Figure 1(b) is the structure of Figure 1(a) following the etching of the BARC layer 70 and the second hardmask layer 60 with the remaining photoresist and BARC stripped. In an embodiment of the instant invention the Ti_(1-x)Al_xN second hardmask layer 60 is etched with a dry plasma etch process comprising BCl₃, Cl₂ and other additives such as N₂ and Ar, and a plasma source power of approximately 800 Watts to 1500 Watts, and a bias power of approximately 50-250 Watts. The flow rates of BCl₃ and Cl₂ are 0-150 sccm and 50-200 sccm respectively and the chamber pressure is approximately 5 mTorr to 20 mTorr.

Following the etching of the second hardmask layer to define the metal trench pattern, the resist 80 and BARC 70

are stripped away in an oxygen-based plasma. Alternative plasma, such as H_2 and/or N_2 , maybe used for photoresist strip. A wet clean is optional to remove possible residues. Following the clean processes, a second BARC layer 75 and a second photoresist layer 85 are formed and patterned on the structure of Figure 1(b) to define the first trench pattern as shown in Figure 1(c). Following the formation of the second patterned photoresist layer 85, BARC layer 75 is etched and the exposed portion of the first hardmask layer 50 and the underlying low k dielectric layer 40 are etched to form a first trench as shown in Figure 1(c). In the case of an OSG low k dielectric film, a $C_4F_8/N_2/CO$ plasma based process can be used with flow rates of 5-10 sccm (C_4F_8), 50-300 sccm (N_2), and 50-200 sccm (CO) with a plasma power source of approximately 900 Watts to 2000 Watts. The photoresist layer 85 will be attacked during the etching processes and will be wholly or partially removed. Following the etching of the OSG film 40, the remaining photoresist layer 85, BARC layer 75, and exposed region of the first hardmask layer 50 are removed resulting in the structure illustrated in Figure 1(d). Alternatively, the photoresist layer 85 and BARC 75 can be stripped before the start of the etching of dielectric layer 40, to reduce the undesired impact to the low k dielectrics 40.

5 The exposed region of the low k dielectric layer is then etched as shown in Figure 1(e) to form a second trench structure which is positioned over the first trench structure. The exposed portion of the etch stop layer 30 is removed and a liner layer 90 and copper region 100 is formed as shown in Figure 1(f). Standard semiconductor process techniques can be used to form the liner layer 90 and copper region 100 such as film deposition and chemical mechanical polishing (CMP). In a further embodiment of the damascene process, the hardmask layers 50 and 60 can be removed using CMP. Typically the copper region 100 is formed by first forming a thick layer of copper followed by CMP processes to remove the excess copper. The removal of the hardmask layers 50 and 60 using CMP can be incorporated into this copper CMP removal process by changing the polishing conditions. In addition to copper any suitable conducting material can be used to fill the trench formed in the low k dielectric.

20

A further embodiment of the instant invention is shown in Figures 2(a) - 2(g). As shown in Figure 2(a) a first etch stop layer 30 is formed over a copper layer 20 and a first dielectric layer 10. The dielectric layer 10 is

formed over a silicon substrate containing various electronic devices such as transistors, diodes, etc. The copper layer 20 represents a portion of the copper interconnect of an integrated circuit which is made up of the electronic devices contained in the silicon substrate. In a multi-level interconnect scheme, layers 10 and 20 described here generally represent the previous interconnect level. The first etch stop layer may comprise silicon nitride (SiN), silicon carbide (SiC), or any suitable material. Following formation of the etch stop layer 30, a first dielectric layer 42 with a low dielectric constant (i.e. less than 3.0) is formed over the etch stop layer 30. In an embodiment of the instant invention this low k dielectric layer 42 comprises organosilicate glass (OSG) which has a dielectric constant of about 2.8. In addition to OSG any suitable low k dielectric material may be used to form the first dielectric layer 42. Following the formation of the first low k dielectric layer 42, a second etch stop layer 110 is formed on the first low k dielectric layer 42. The second etch stop layer may comprise silicon nitride (SiN), silicon carbide (SiC), or any suitable material. A second low k dielectric film (i.e. dielectric constant less than 3.0) 44 is formed on the second etch stop layer 110. In an embodiment of the instant

invention the second low k dielectric film will comprise OSG or other suitable materials. A first hardmask layer 50 is formed on the second low k dielectric film 44. This first hardmask layer 50 comprises a material selected from the group consisting of silicon carbide (SiC), silicon nitride (SiN), and any other suitable material. Following the formation of the first hardmask layer 50 a second hardmask layer 60 is formed on the first hardmask layer. This second hardmask layer comprises a material selected from the group consisting of titanium aluminide (TiAl), titanium aluminum nitride (TiAlN), titanium nitride (TiN), aluminum nitride (AlN), tantalum aluminide (TaAl), tantalum aluminum nitride (TaAlN), or any combination of layers of these various alloys. In an embodiment of the instant invention $Ti_{(1-x)}Al_xN$ is used with x varying from 0 to 100% and more preferably from 25% to 40%. For a $Ti_{(1-x)}Al_xN$ film where x varies from 25% to 40% the etch rate selectivity of OSG to $Ti_{(1-x)}Al_xN$ is approximately 15:1. Thus, the OSG film will etch approximately fifteen times faster than the $Ti_{(1-x)}Al_xN$ film. Following the formation of the second hardmask layer 60, a layer of bottom antireflective coating (BARC) 70 and a photoresist layer 80 is formed and patterned as shown in Figure 2(a). The BARC 70 is an optional layer.

Shown in Figure 2(b) is the structure of Figure 2(a) following the etching of the BARC layer 70 and the second hardmask layer 60 followed by resist and BARC stripping. In an embodiment of the instant invention the $\text{Ti}_{(1-x)}\text{Al}_x\text{N}$ second hardmask layer 60 is etched with a dry plasma etch process comprising BCl_3 , Cl_2 and other additives such as N_2 and Ar, and a plasma source power of approximately 800 Watts to 1500 Watts, and a bias power of approximately 50-250 Watts. The flow rates of BCl_3 and Cl_2 are 0-150 sccm and 50-200 sccm, respectively and the chamber pressure is approximately 5-20 mTorr.

Following the etching of the second hardmask layer, the resist 80 and BARC 70 are stripped away in an oxygen-based plasma. Alternative plasma, such as H_2 and/or N_2 , may also be used for photoresist strip. A wet clean is optional to remove possible residues. Following the clean processes a second BARC layer 75 and a second photoresist layer 85 are formed and patterned on the structure of Figure 2(b) as shown in Figure 2(c). Following the formation of the second patterned photoresist layer 85, the exposed portion of the first hardmask layer 50 is etched and the resist 85 and BARC 75 layers are stripped in an H_2 or N_2 plasma. Oxygen

plasma may need to be avoided for resist strip if it changes the properties of the low k dielectric layer 44. A wet clean is optional after resist strip to remove any etch residues. In the case of via-to-trench misalignment, an additional second hardmask etch is needed prior to the first hardmask via opening etch.

Following the removal of the photoresist 85 and BARC 75 layers, the low k dielectric layer 44 is etched as shown in Figure 2(d). In the case of the second OSG low k dielectric film 44, a $C_4F_8/N_2/CO$ plasma based process can be used with flow rates of 5-10 sccm C_4F_8 , 50-300 sccm N_2 , and 50-200 sccm CO with a plasma power source of approximately 900 Watts to 2000 Watts. The etch stops on the second etch stop layer 110, as shown in Fig. 2(d)

The exposed region of the second etch stop layer 110 and the exposed portion of the first hardmask 50 are now removed using the second hardmask 60 as etch mask as shown in Fig 2(e). The exposed portions of the low k dielectric layers 44 and 42 are then etched simultaneously. The etching process is completed when the etch stop layer 110 is reached in the trench portion and etch stop layer 30 is reached in the via portion as shown in Fig 2(f). The

exposed portion of the etch stop layer 30 is removed, and the exposed portion of the trench etch stop layer 110 may be etched as well. A liner layer 90 and copper region 100 is formed as shown in Figure 2(g). Standard semiconductor process techniques can be used to form the liner layer 90 and copper region 100 such as film deposition and chemical mechanical polishing (CMP). In a further embodiment of the damascene process, the hardmask layers 50 and 60 can be removed using CMP. Typically the copper region 100 is formed by first forming a thick layer of copper followed by CMP processes to remove the excess copper. The removal of the hardmask layers 50 and 60 using CMP can be incorporated into this copper CMP removal process by changing the polishing conditions. In addition to copper, any suitable conducting material can be used to fill the various trench structures.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments, as well as other embodiments of the invention will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that

the appended claims encompass any such modifications or
embodiments.

FOUO" 9770660